

Mechanical design of multiple zone plates precision alignment apparatus for hard x-ray focusing in twenty-nanometer scale

Deming Shu, Jie Liu, Sophie-Charlotte Gleber, Joan Vila-Comamala, Barry Lai, Jorg Maser, Christian Roehrig, Michael J. Wojcik, and Stefan Vogt²

**Advanced Photon Source
Argonne National Laboratory
Argonne, IL 60439, U.S.A.**

MEDSI 2014, Oct. 23, 2014, Melbourne, Australia

OUTLINE

- Introduction
- Alignment apparatus Z2-33 for two zone plates
- Alignment apparatus Z2-34 for three zone plates with K-B mirror system
 - Design approach for thermal-mechanical displacement compensation in nanometer scale
- Alignment apparatus Z2-37 for three, six or more zone plates
- Summary



Introduction

- Fresnel-zone-plate-based optics is extensively applied for x-ray instruments [1]. At the Advanced Photon Source (APS) at Argonne National Laboratory (ANL), many synchrotron radiation beamlines are using Fresnel zone plates for hard x-ray focusing.
- However, the efficiency of Fresnel zone plates (FZPs) as focusing optics for x-rays depends on the height of the structures. In the hard x-ray regime, very high aspect ratios are required for maximum efficiency with focusing spot sizes of few tens of nanometers, which is required for future hard x-ray nanoprobe beamlines planned as part of the APS Upgrade project [2,3].
- To overcome the limitations of today's fabrication techniques for high-efficiency hard x-ray FZPs, a new approach of stacking FZPs at larger distances (in an intermediate-field) was proposed by Vila-Comamala et al. in 2012 [4].



Introduction

- According to this new approach, stacking zone plates with large separation distance is possible by adjusting the diameter of the downstream FZP so that its focal length is equal to the focal length of the upstream FZP minus the distance between both FZPs.
- However, besides designing and fabricating of high quality FZPs for intermediate-field stacking, there are many mechanical design challenges to transfer the theory to a practical instrument.

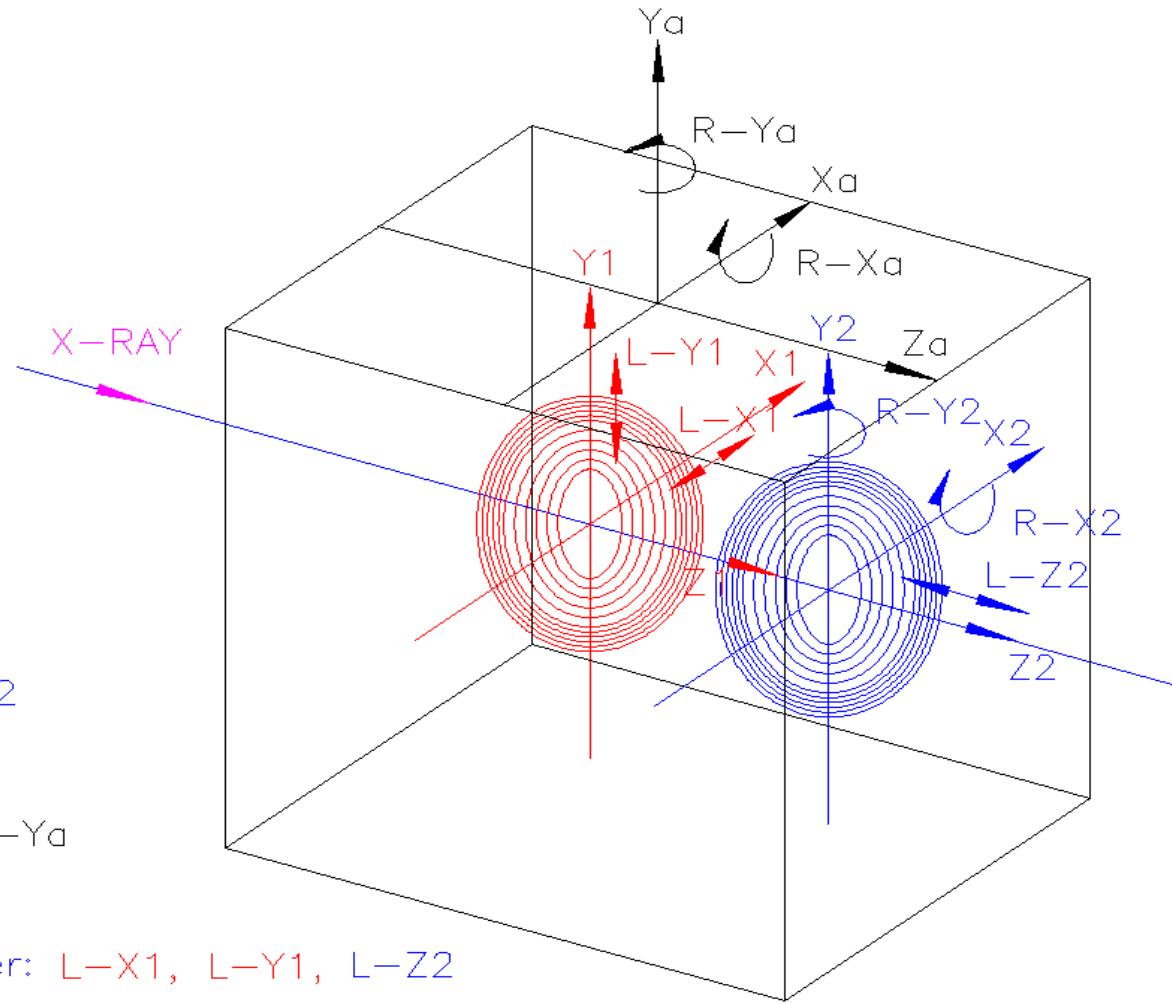
Introduction

A precision alignment apparatus for multiple FZPs handling and aligning must be designed to meet the following challenging design requirements:

- Each of the stacking FZPs needs to be manipulated in three dimensions with nanometer-scale resolution and several millimeters travel range.
- The relative three-dimensional stabilities between all of the stacking FZPs (especially in the x-ray beam transverse plane) are required to be kept within few nanometers for more than eight hours, the duration of a typical hard x-ray nanoprobe operation.
- Compatible with the operation of multiple optics configuration for the APS future x-ray nanoprobe design.



Alignment apparatus for two zone plates (Z2-33)



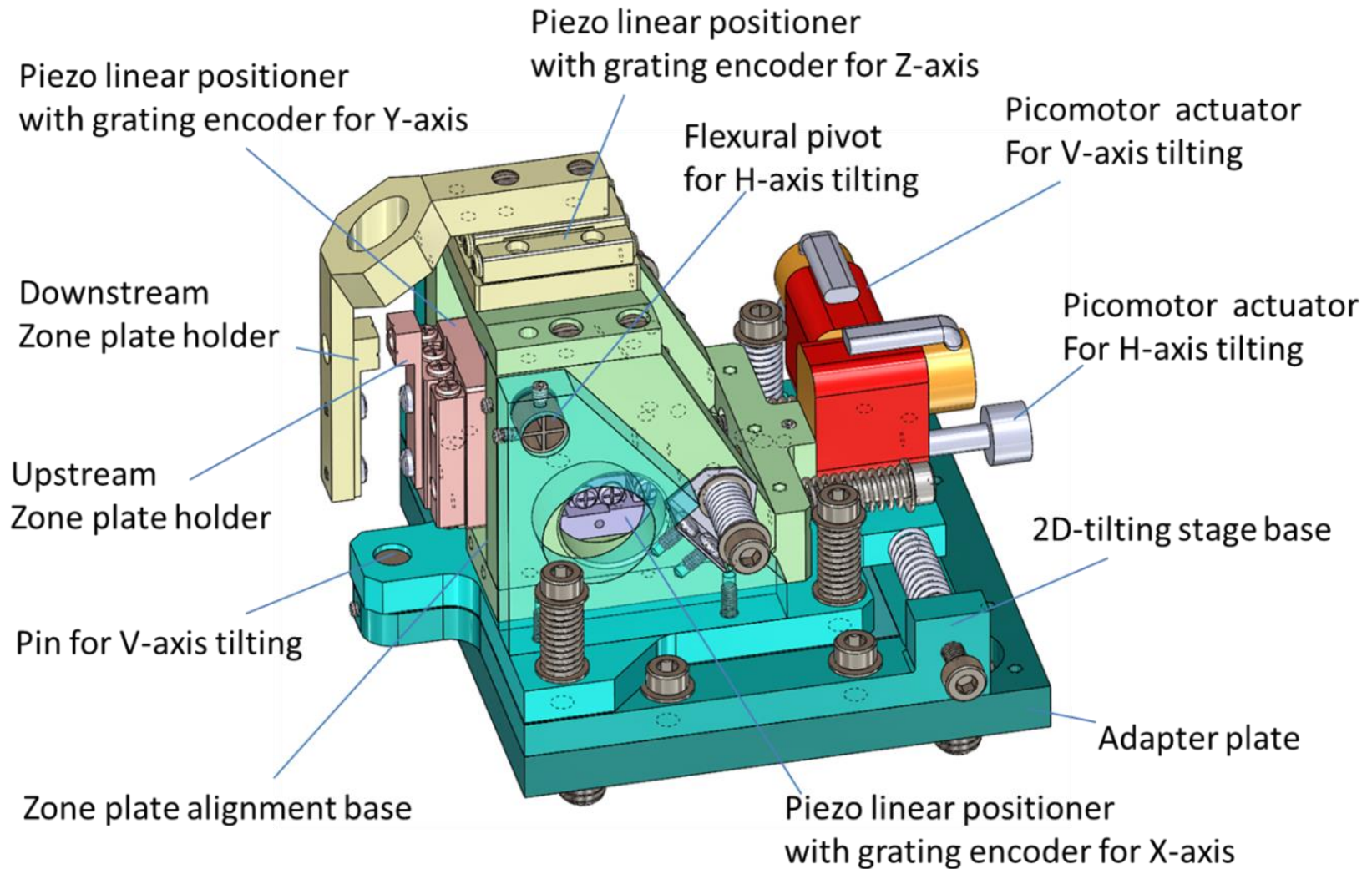
Manual: R-X2, R-Y2

Motorized: R-Xa, R-Ya

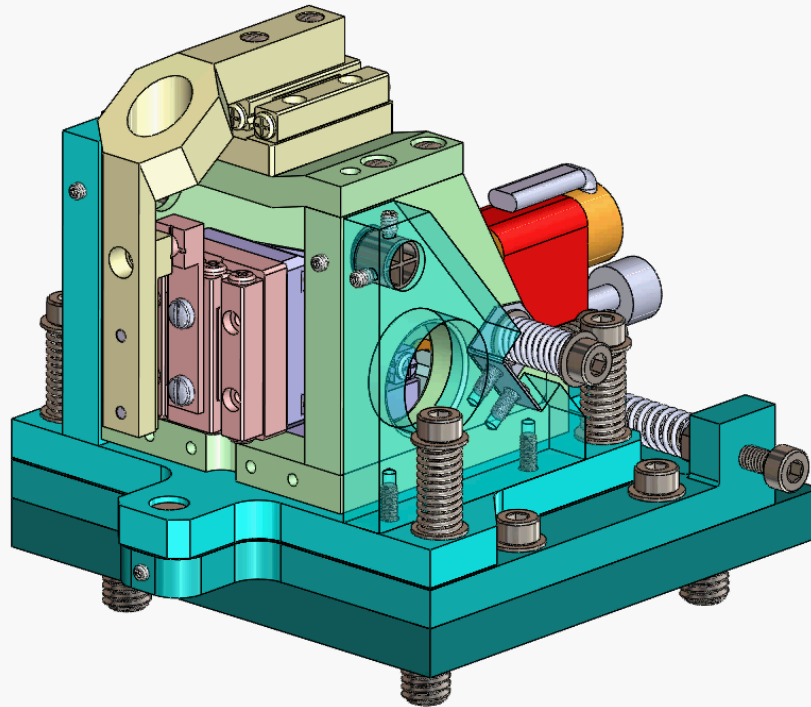
Motorized w/Encoder: L-X1, L-Y1, L-Z2



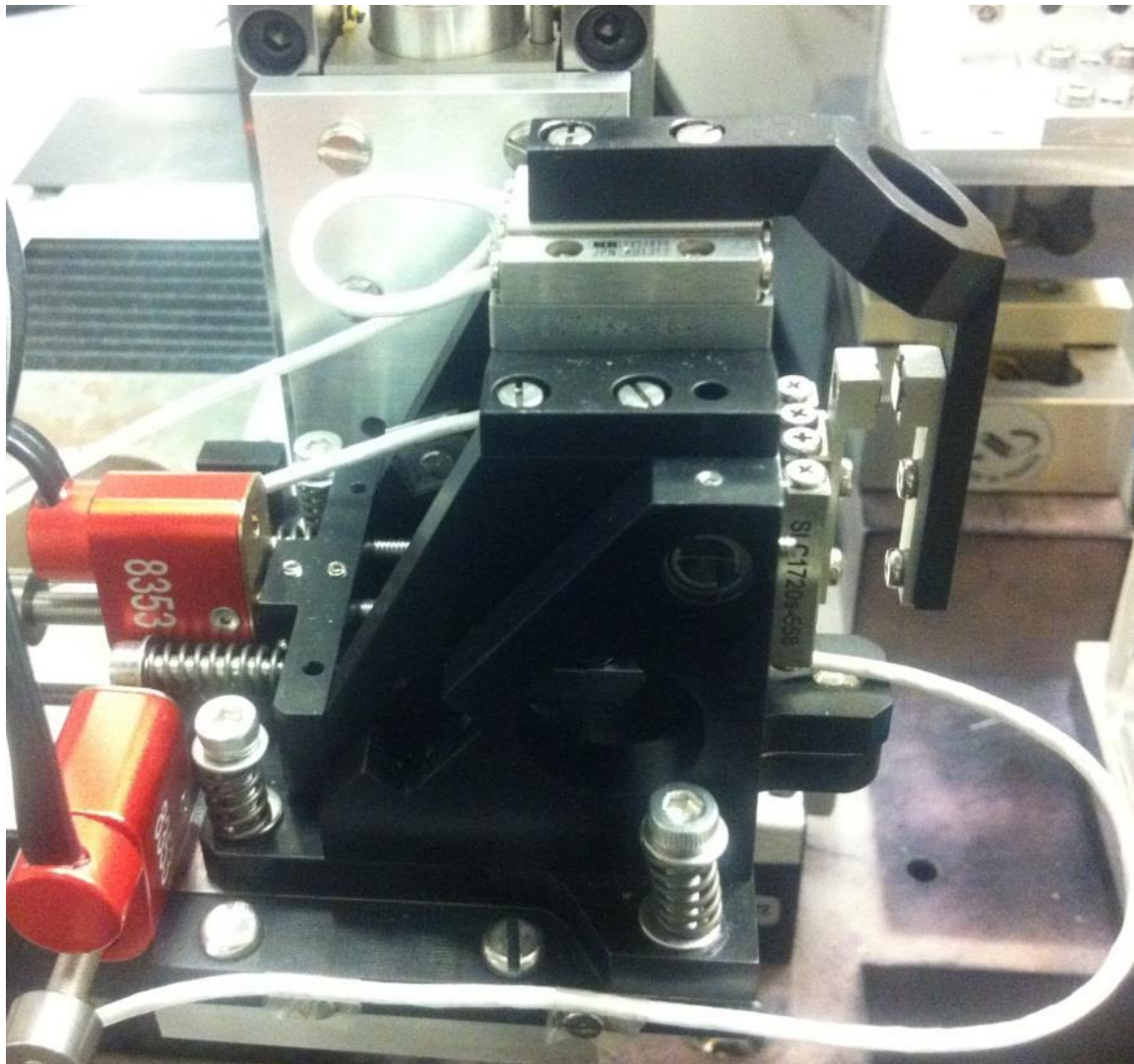
Alignment apparatus for two zone plates (Z2-33)



Alignment apparatus for two zone plates (Z2-33)



Alignment apparatus for two zone plates (Z2-33)



SmarAct SLC-1720-S



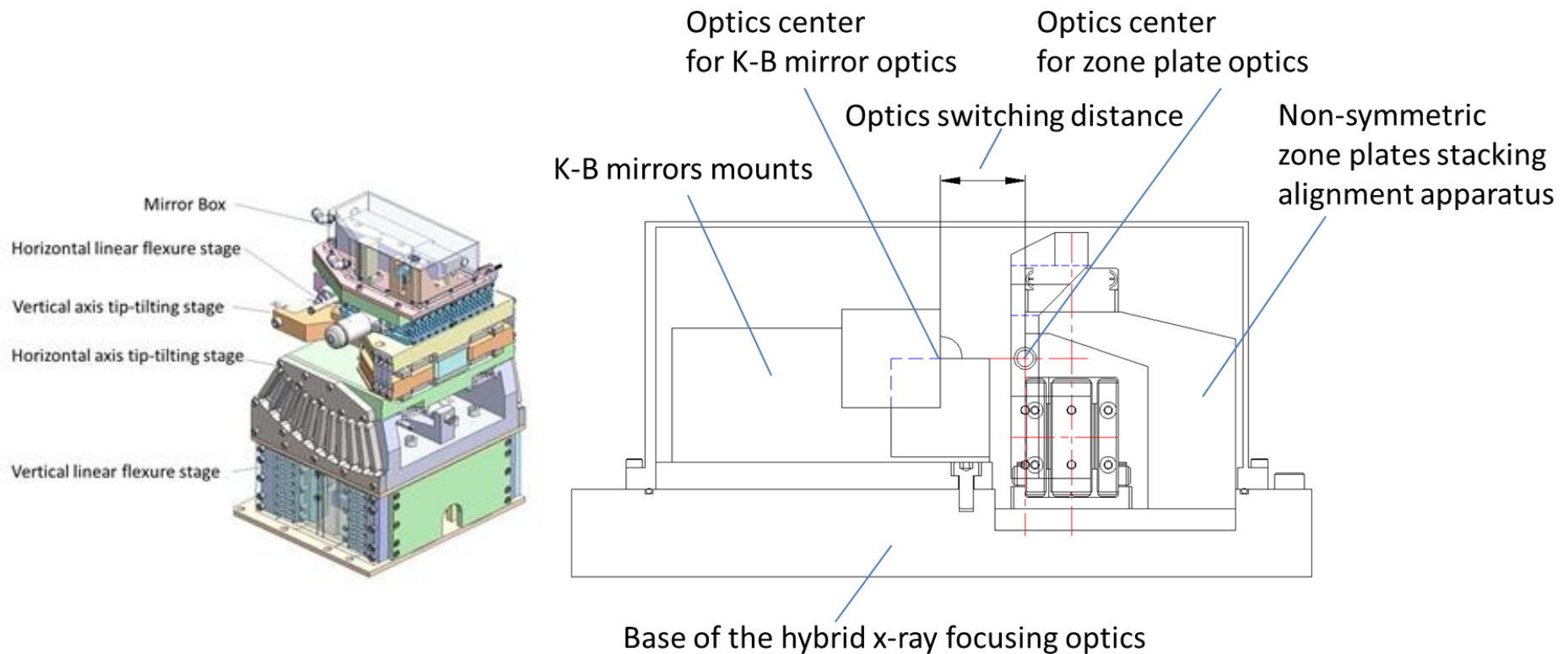
- Dimensions: 22 x 17 x 8.5 mm³
- Travel: about 12 mm
- Weight: about 13 g
- Allowable load: 40 N
- Integrated nanosensor
- Options:
 - Vacuum compatibility: HV, UHV
 - Non-magnetic
- Velocity: max. 8mm/s
- Step width: between 50nm and 500nm
- Scanning range: about 750nm
- Resolution: sub-nanometer

Load

- Load: 40N
- horizontal and vertical application possible

Courtesy of: SmarAct

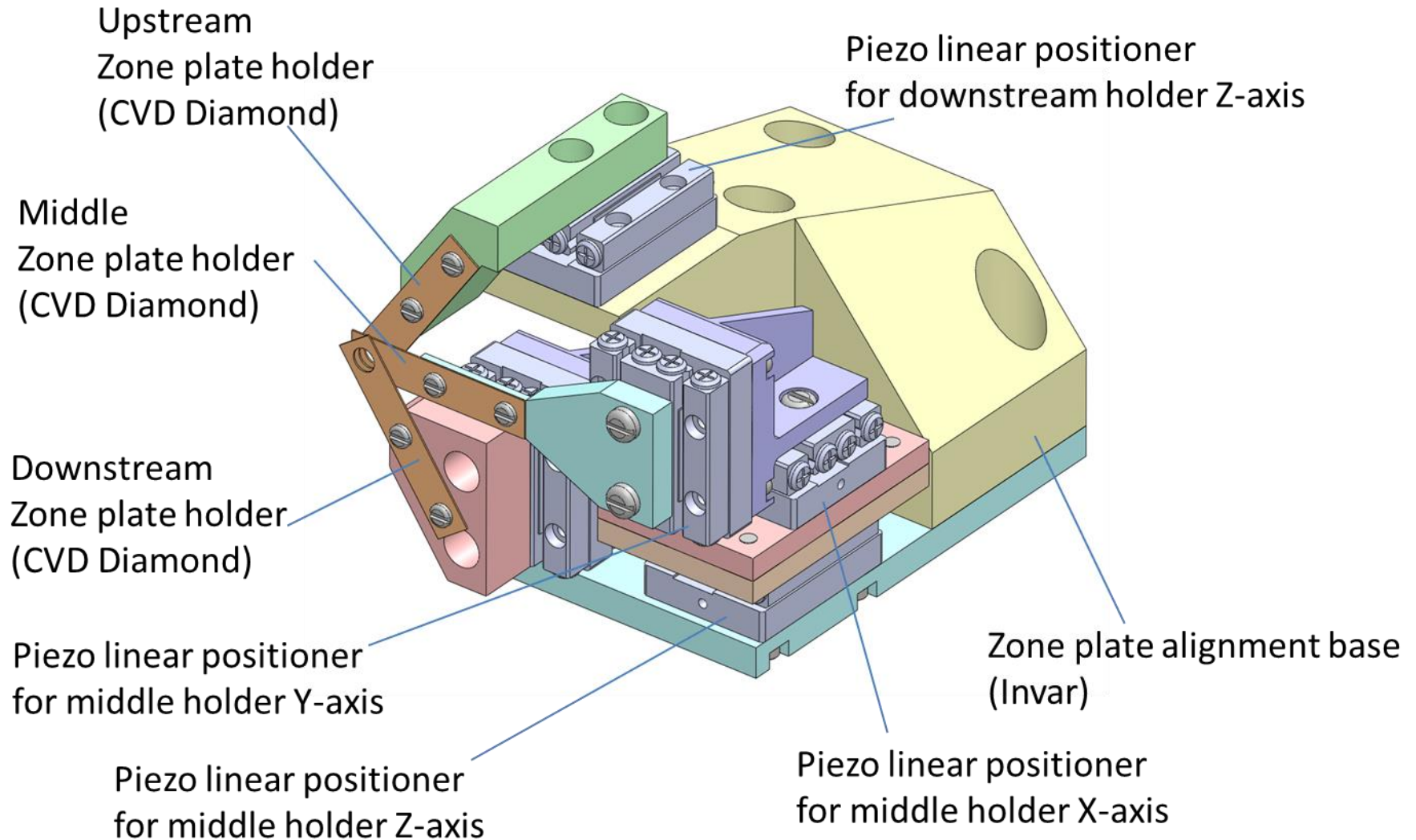
Alignment apparatus for two zone plates with K-B mirror system



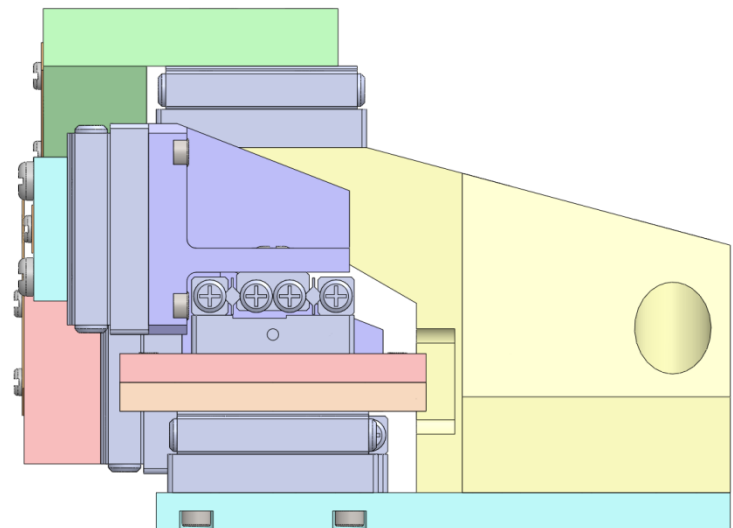
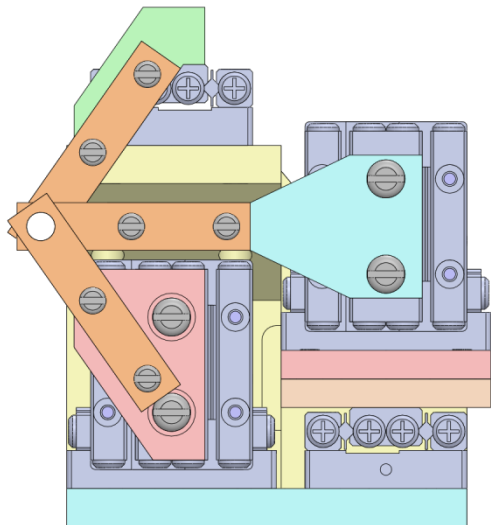
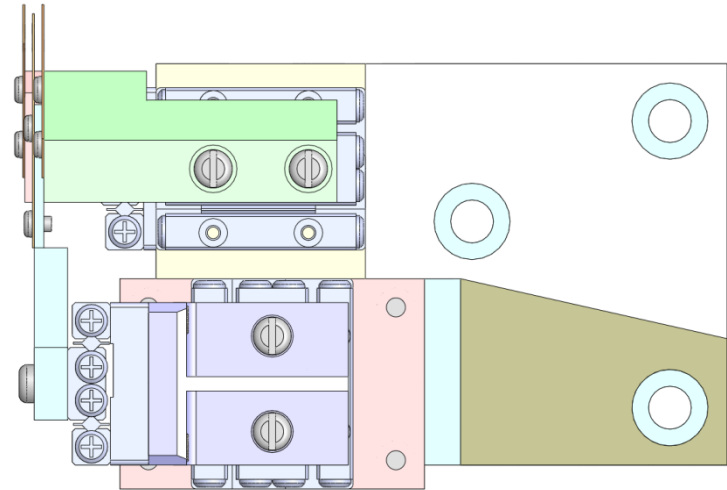
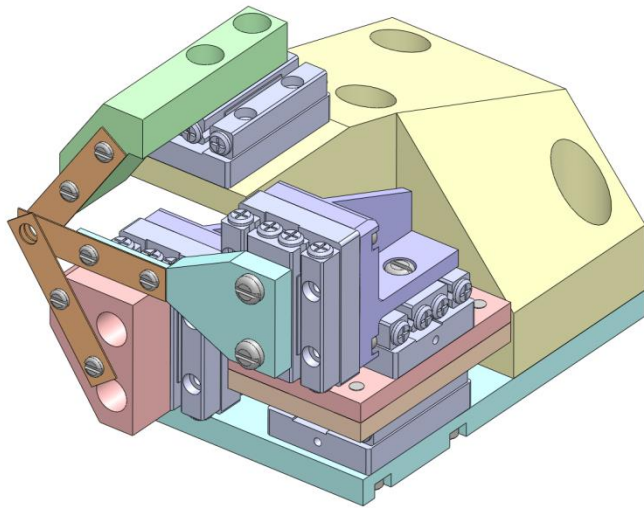
A non-symmetric alignment apparatus structure has been developed for the hard x-ray nanoprobe with hybrid hard x-ray focusing optics, which needs stacking zone plates optics to be switchable with K-B mirror based optics with a minimized horizontal switching distance (< 16 mm). In this configuration, the zone plate optics and K-B mirror optics will share a high-stiffness flexure-based 2D-tilting stage through the base of the hybrid x-ray focusing optics [6].



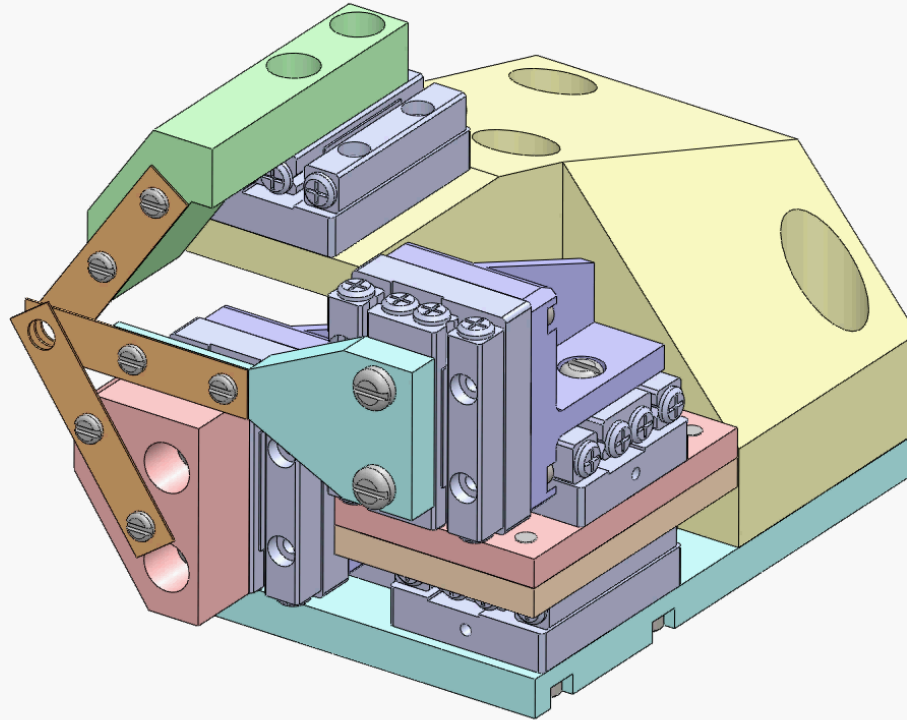
Alignment apparatus using CVD diamond holder for three zone plates compatible with K-B mirror system (Z2-34)



Alignment apparatus for three zone plates compatible with K-B mirror system (Z2-34)



Alignment apparatus for three zone plates compatible with K-B mirror system (Z2-34)

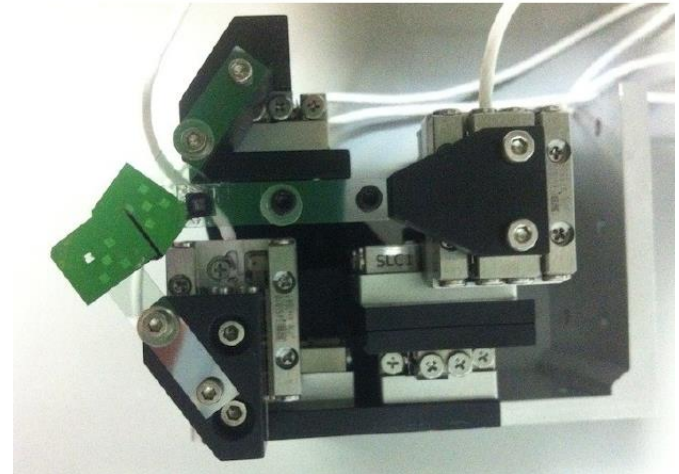
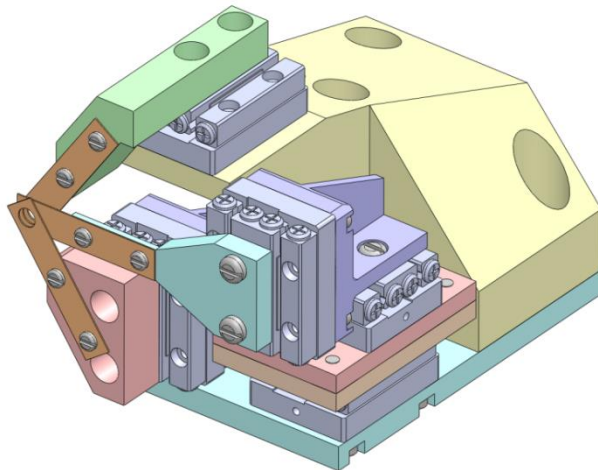


Alignment apparatus for three zone plates compatible with K-B mirror system (Z2-34)

Diffraction efficiency measurements

Mount 150 μ m US pinhole and 30 μ m OSA, **theoretical/measured** values

	Tot height	@10keV	@11.8keV	focus@11.8keV
Optimum height		1.99 μ m	2.55 μ m	
USZP	0.8 μ m	12.1 9.3%	8.0 6.9%	210nm
CZP	0.8 μ m	12.1 10.6%	9.0 7.7%	220nm
DSZP	0.9 μ m	14.6 13.8%	9.9 9.6%	180nm
USZP&CZP	1.6 μ m	29.9 17.4%	23.9 14.3%	na
USZP&DSZP	1.7 μ m	31.2 20.2%	25.8 19.4%	na



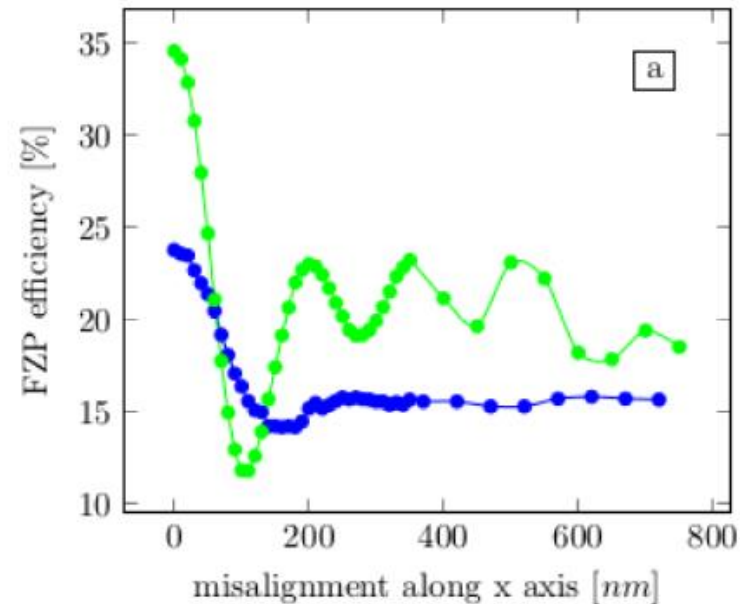
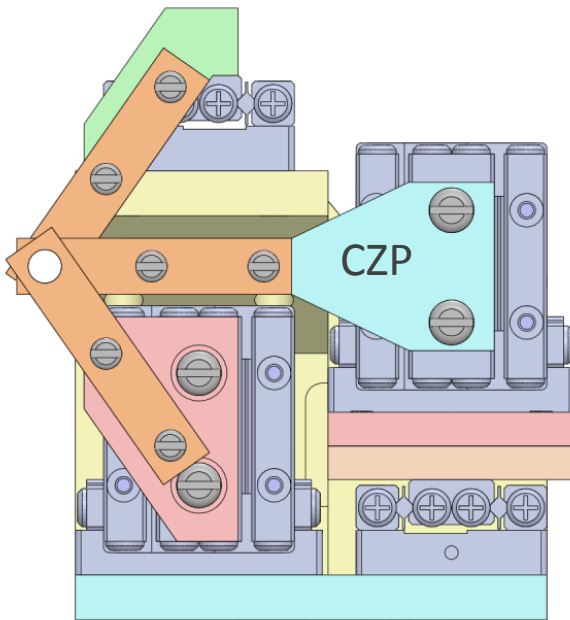
S-C. Gleber and et al, to be published on Optics express.



Alignment apparatus for three zone plates compatible with K-B mirror system (Z2-34)

Influence of ZP lateral misalignment

Start with stack of 3 ZPs and move CZP out in x in 10 and then 50nm steps



FZPs misalignment with thermal drifting need to be controlled to the level of $< 10 - 20\%$ of the FZP outmost zone width

Alignment apparatus for three zone plates compatible with K-B mirror system (Z2-34)

FEA results showed:

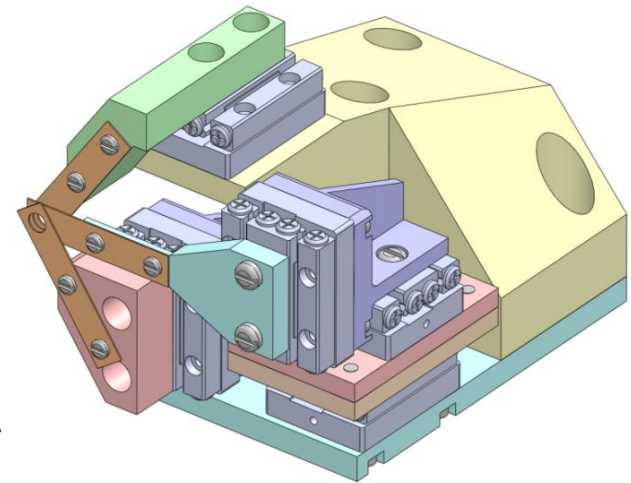
with CVD diamond holders, Invar-36 parts and commercial stages

- ~ 100 nm zone plate thermal drifting in X direction under 1 °C temperature variation
- ~ 250 nm zone plate thermal drifting in Y direction under 1 °C temperature variation

X-ray experiment at APS 2-ID-E showed:

Using Z2-34 with 3 FZPs stacking

- an 3-fold increase of efficiency at 11.8 keV has been demonstrated at APS 2-ID-E with ~200 nm x-ray focal spot.
- It is OK for zone plates for ~ 200 nm focal spot with +/- 0.1 °C temperature variation

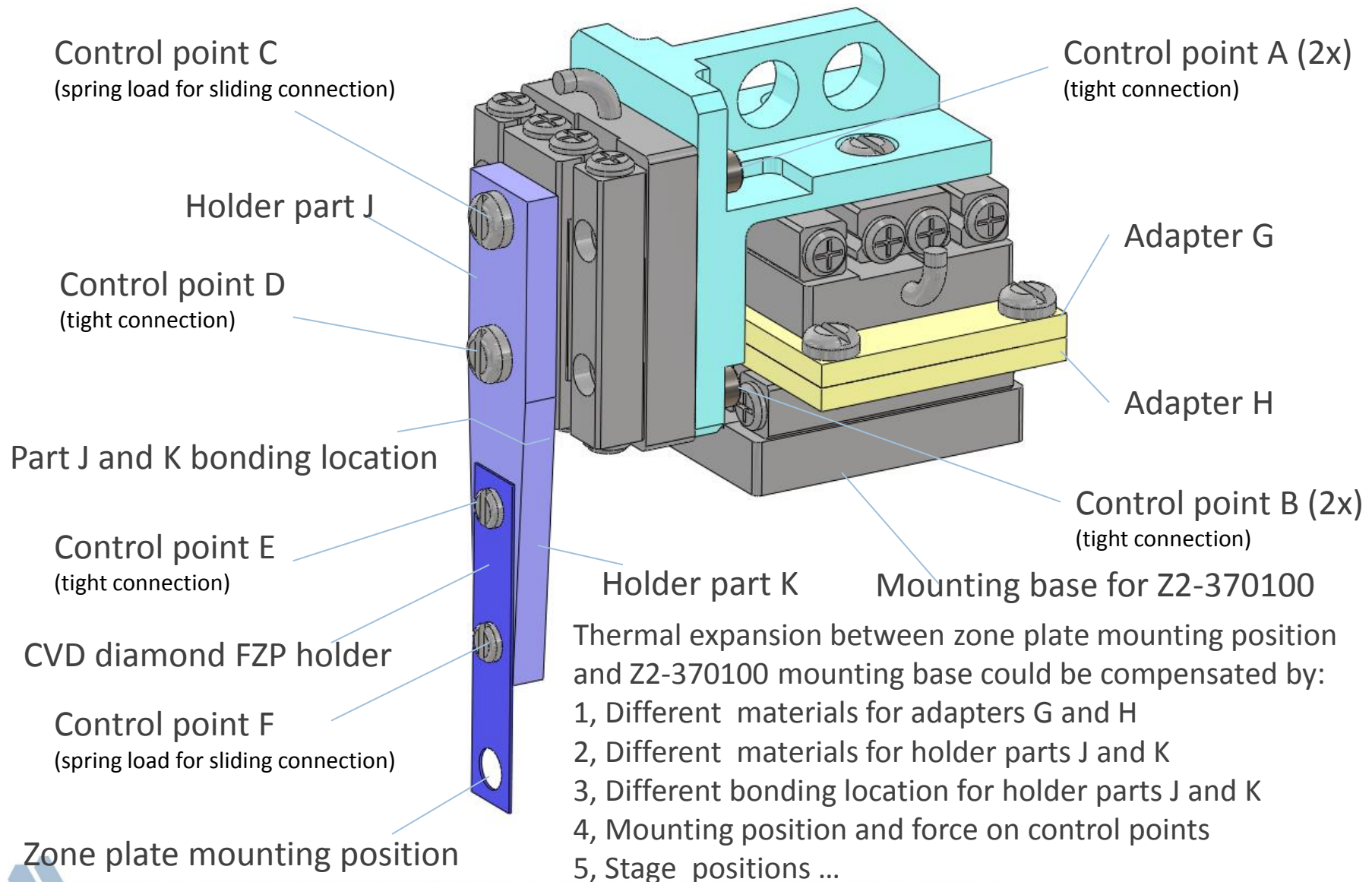


It is OK for ~ 200 nm x-ray focal spot operation with +/- 0.1 °C temperature variation. However, for 20-nm-scale hard x-ray focusing, Z2-34 will need stages to be customized with Invar structures.

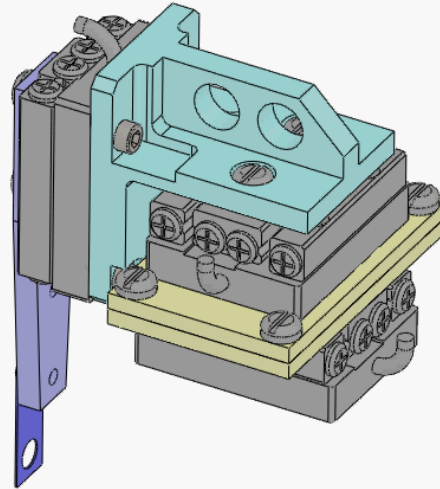


Design approach for thermal drifting compensation in nanometer scale

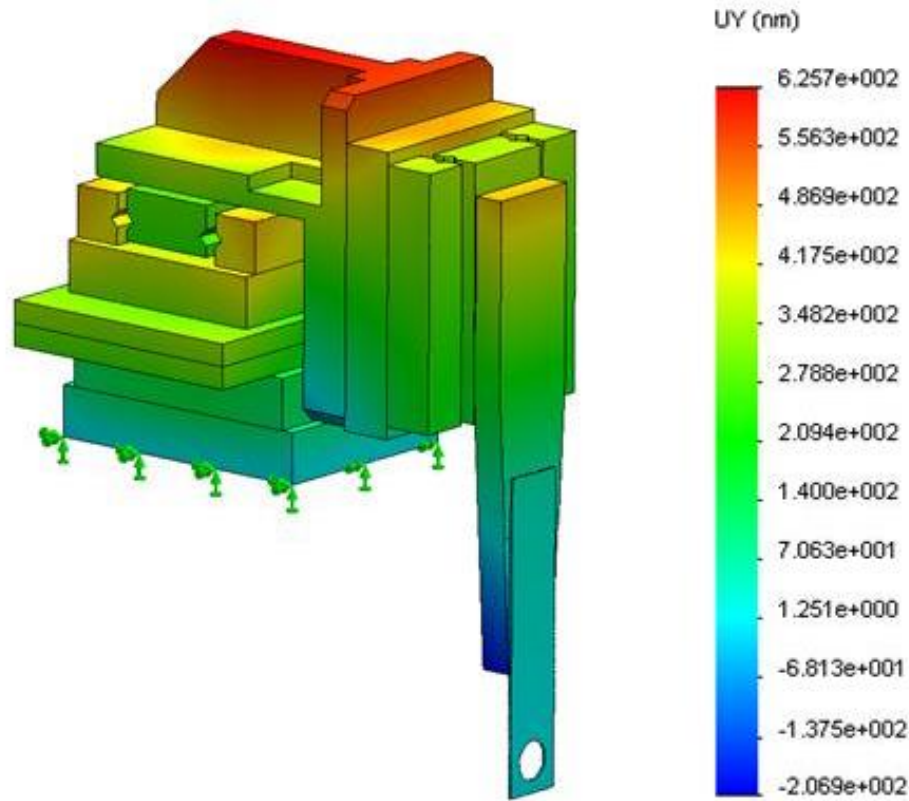
Z2-370100 CVD Diamond FZP holder and stages module



Alignment apparatus for multiple zone plates (Z2-37)



Alignment apparatus for multiple zone plates (Z2-37)



Y-Stage Position (mm)	Y (nm)
1.0	-6.5
0	-2.3
-0.5	-0.61
-0.6	-0.61
-0.7	-0.17
-0.75	0.061
-0.8	0.24
-1.0	1.4

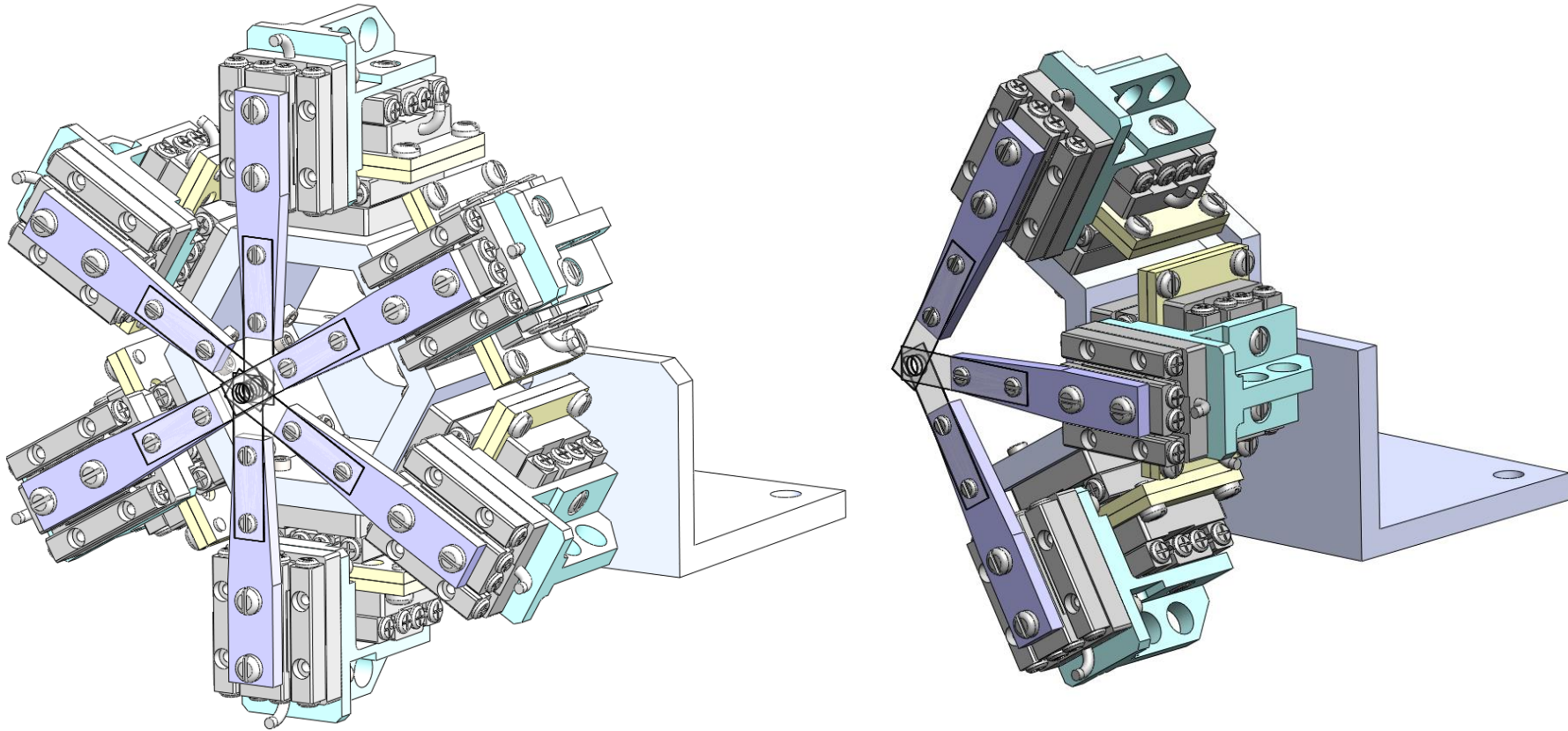
3-D Solidworks™ FEA results for zone plate thermal drifting in Y direction under 1 °C temperature variation with different Y-stage positions. In this study, the linkage material is SS304 and the adapters material is AL6061.

A 3-D Solidworks™ FEA model of the Z2-3701 X-Y-Z stages sub-assembly module for thermal drifting in Y direction under a 1 °C temperature variation at y-stage neutral position.

More detailed FEA results to be presented in the MEDSI-2014 paper:

J. Liu and et al, FE Study of Thermal Stability of the Multiple Fresnel Zone Plates Precision Alignment Apparatus for Hard X-Ray Focusing

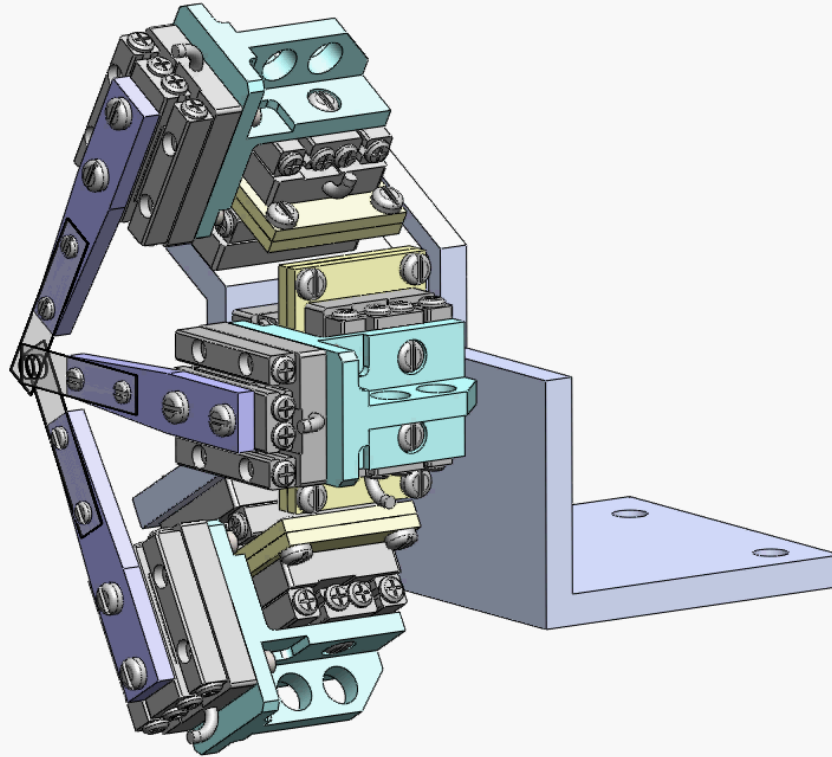
Alignment apparatus for multiple zone plates (Z2-37)



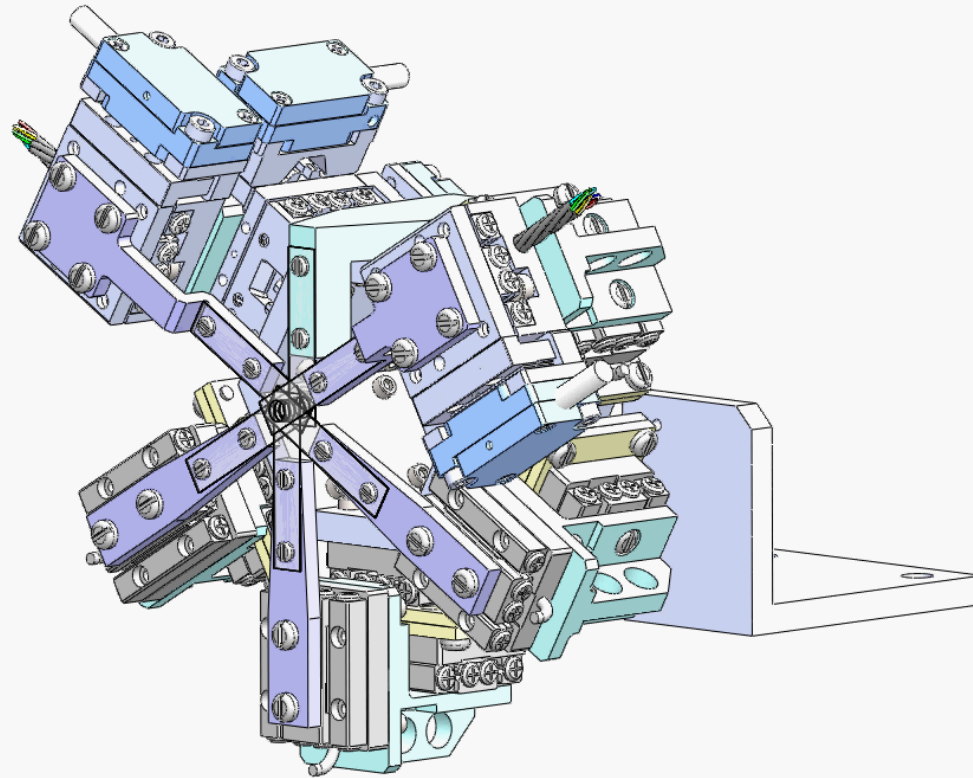
D. Shu, J. Liu, S. C. Gleber, B. Lai, J. Maser, C. Roehrig, M. J. Wojcik, and S. Vogt,
U. S. Patent application in progress for ANL-IN-13-092.



Alignment apparatus for multiple zone plates (Z2-37)



Alignment apparatus for multiple zone plates (Z2-37)



In 2-ID-D test setup, the Z2-37 invar base is mounted on a large stepping-motor-driven X-Y-Z stage system associated with a four Z2-3701 X-Y-Z stage module using SmarAct™ SLC-1720S Piezo-motor-driven stages and one set of Z2-3704 X-Y-Z stages module using Micronix™ PPS-20 Piezo-motor-driven stages.

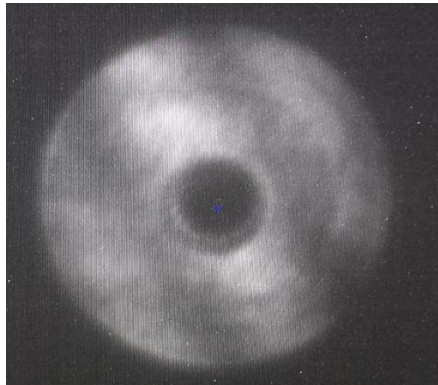
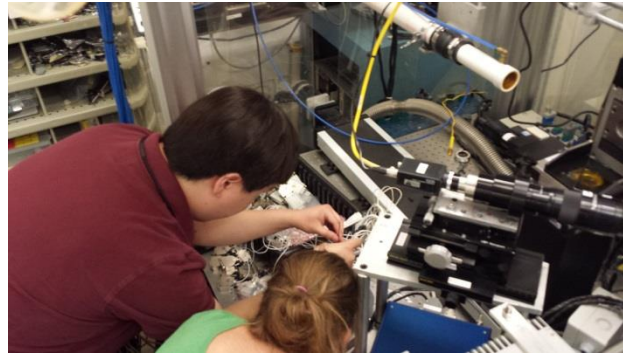
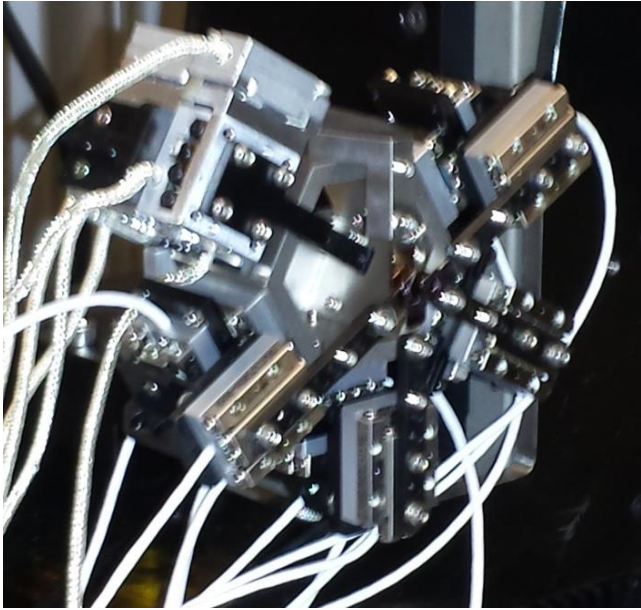
Alignment apparatus for multiple zone plates (Z2-37)

Instalation at APS 2-ID-D with Z2-37 on July 3, 2014



Alignment apparatus for multiple zone plates (Z2-37)

Installation at APS 2-ID-D with Z2-37 on July 3, 2014



Alignment apparatus for multiple zone plates (Z2-37)

First user operation at APS 2-ID-D with Z2-37 on July 8, 2014

Mechanically stack up to five FZPs, which resulted in an 6 - 8-fold increase of efficiency at 22.5 and 25 keV, has been demonstrated at APS sector 2.

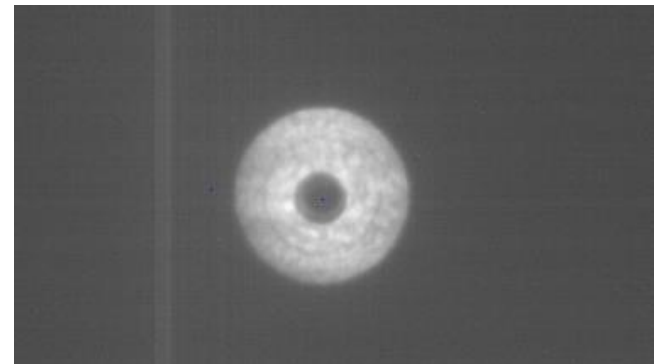
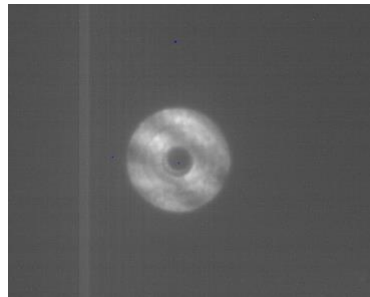
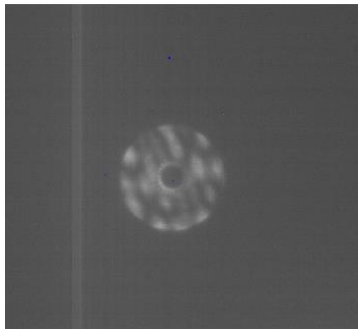
First user operation with 22.5 keV and 200 nm – 300 nm x-ray focal spot started on July 8, 2014.

July 8, 08:06 am

July 8, 08:35 am

July 8, 09:08 am

(after 4 days APS machine studies)



More detailed x-ray experimental results to be presented for the XRM-2014, Melbourne:

S. Vogt, "High Efficiency for Hard X-Ray Focusing by Multiple Zone Plate Stacking in the Intermediate Field", Poster Board Number: 6, Poster, Poster Session 2, Thursday, October 30 2014, 1630 – 1900.

and S-C. Gleber et al, to be published on Optics express.

Summary

- Intermediate-field stacking approaches with diameter adjusted FZPs have been studied theoretically and experimentally at the APS.
- The novelty of this new mechanical design is the compactness and positioning stability of its unique structural arrangement.
- With multiple arrays of FZPs, the stacking apparatus provides a versatile way of varying focus spot size requirements and a wide range of incident energy.
- Mechanically stack up to five FZPs, which resulted in an 8-fold increase of efficiency at 25 keV, has been demonstrated at APS sector 2 for user operations with 200 nm – 300 nm x-ray focal spot.
- Experiment with high resolution focusing FZPs for hard x-ray focusing in twenty-nanometer scale is on the way.



References

- [1] J. Kirz, “Phase zone plates for x rays and the extreme uv,” J. Opt. Soc. Am. 64, 301–309 (1974).
- [2] [http://www.aps.anl.gov/Upgrade/APS Upgrade project](http://www.aps.anl.gov/Upgrade/APS%20Upgrade%20project).
- [3] J. Maser, B. Lai, T. Buonassisi, Z. Cai, C. Si, L. A. Finney, C. Gleber, C. Jacobsen, C. A. Preissner, C. Roehrig, V. Rose, D. Shu, D. Vine, S. Vogt, Metallurgical and Materials Transactions A, Volume 45, Issue 1, pp 85-97, 2014.
- [4] J. Vila-Comamala, M. Wojcik, A. Diaz, M. Guizar-Sicairos, C. M. Kewish, S. Wang, & C. David, (2012). J. Synchrotron Rad. 20, 397–404.
- [5] S. Gleber, M. Wojcik, J. Liu, C. Roehrig, M. Cummings, J. Vila-Comamala, K. Li, B. Lai, D. Shu and S. Vogt, submitted for Optics Express, 2014.
- [6] D. Shu, J. Liu, S. C. Gleber, B. Lai, J. Maser, C. Roehrig, M. J. Wojcik, and S. Vogt, U. S. Patent application in progress for ANL-IN-13-092.
- [7] P. Kirkpartrick, and A. V. Baez, Formation of Optical Images by X-Rays. JOSA. 1948; 38(9): 766-773.



Acknowledgement

The authors would like to thank S. Keaney, J. Anton, C. Jacobsen and G. Pile from ANL for their help in the development of this project. This research used resources of the Advanced Photon Source and Center for Nanoscale Materials, U.S. Department of Energy (DOE) Office of Science User Facilities operated for the DOE Office of Science by Argonne National Laboratory under Contract No. DE-AC02-06CH11357.

THANKS FOR YOUR ATTENTION

